Working

2002 Elemental Analyses of

Boundary Waters Canoe Area Lichens

of the

Superior National Forest, Minnesota

Final Report

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ABSTRACT

In the 1986 report on the lichens and air quality in the Boundary Waters Canoe Area it was recommended that a restudy of the elemental analyses of lichens be done every five years. A restudy was done in 1992 and 1997. The present report is on the third restudy done in 2002 using the same methods, species and localities. The most significant finding of the fourth sampling is a dramatic decrease in Pb content in the lichens, which continues to decline and not level off. There is also a consistent upward trend in alkali and alkaline earth metals which is unexplained. Sodium shows a significant decrease from west to east, suggesting a source near Lac La Croix. Isabella Lake continues to show high concentrations of some elements. *Hypogymnia physodes*, an important biomonitoring species in this study, continues to show elevated levels of Ca, Mg and Mn.

INTRODUCTION

Lichens are able to accumulate chemical elements in the excess of their metabolic needs depending on the levels in the substrate and air and, since lichens are slow growing and long lived, they serve as good summarizers of the environmental conditions in which they are growing. Chemical analysis of the thallus of lichens growing in areas of high fallout of certain elements will show elevated levels in the thallus. Toxic substances (such as sulfur) are also accumulated and determination of the levels of these toxic elements can provide indications of sub-lethal but elevated levels in the air (Wetmore, 1987).

During 1986 a complete study of lichens and air quality was done in the Boundary Waters Canoe Area (BWCA) in northern Minnesota, including a species list and elemental analysis of three species at six localities. The report showed no elevated accumulation of elements at any locality. The report recommended that a restudy of elemental analysis be done every five years.

In 1992 and 1997 all six of the elemental analysis localities used in the earlier studies

were revisited for new collections. One lichen species was added (*Parmelia sulcata*) to the original species list for a better comparison with other regional studies (Wetmore 1984, 1985, 1992). The results of this study up to 1997 have been published in a peer reviewed journal (Bennett & Wetmore, 1999). During July 2002 the same sites were visited and the same four species were collected for analysis.

METHODS

Methods used in the present study were the same as those of the previous studies (Wetmore 1987, 1993, 1998). All six of the previous localities were sampled again in July 2002. At each locality a bag of each species was collected from branches of conifers. In all cases collections came from many trees to provide enough material. Lichens were cleaned but not washed. Three replicates were obtained from each bag of each species for each locality. Multielement analysis was by ICP and sulfur by infra red absorption. In the original study three species were analyzed (*Cladina rangiferina, Evernia mesomorpha,* and *Hypogymnia physodes*). In all of the subsequent restudies *Parmelia sulcata* was added to provide a better comparison with other regional studies. Standards were also included with the unknowns and were National Bureau of Standards SRM 1547 (peach leaves) and a locally used lichen standard (*Cladina stellaris*) during the instrument runs.

Seventy-eight lichen samples were collected in 2002 and analyzed for 16 elements. The results are shown in Appendix 2. Sixty-two below detection limit values were found for Cd, Cr, Ni and Pb and were deleted, resulting in 1,186 data points for analysis. These data were merged with the data from the three prior sampling periods into one file for analysis, which contained 3,958 data points across the four years of sampling.

Analysis of all elements across 16 years of sampling, six localities and four species is complex and difficult to do. Many patterns and trends are found that are not easy to interpret. So many conventional statistical analyses are executed that the underlying assumptions of independence are violated. Consequently, multivariate analysis techniques were used instead, as described in our earlier reports. The elemental data are correlated, then reduced to a small

number of factors using factor analysis. The factors are linear combinations of elements that are correlated with one another. A factor that contains Al and Fe, for example, is considered a soil factor because that is the origin of these elements.

In 2002, the latitude and longitude of each locality was determined with a GPS. The results are shown in Appendix 1.

RESULTS AND DISCUSSION

Means by species by year by locality by element are in Appendix 3. These are presented for reference purposes only and will not be discussed, with one exception (below).

Our first analysis was to repeat the identical two-factor principal components analysis on the four years data set that was performed on the three years data set for the 1997 report (Table 1). The two components accounted for 67% of the total variance, almost the same amount as for the three-year data set. The loadings and the positions of the elements on the components were virtually identical to the components extracted from the three-year data set.

The scores for the two factors were computed and are plotted in Figs. 1-2. Factor 1 has begun a slight decline since 1997, while Factor 2 has returned almost to the levels of 1992 after increasing in 1997, although a regression analysis of this factor indicates a moderate increase over all four years. Factor 1 still declines from west to east, while Factor 2 continues a moderate increase. Isabella Lake continues to show an unusually high loading on Factor 2. Scores for both factors differed statistically significantly over years and localities (F probabilities < 0.000 except Factor 1 over years was 0.022) using three-way analyses of variance.

These results differed little from the previous results, and the changes in Pb concentrations were not revealed . Therefore it was decided to attempt to improve the analysis to account for more of the data. Cluster analyses by species revealed that the *Evernia* data were grouped very differently from the data of the other three species. Consequently, this species was not analyzed further in the data set. The resulting 3 species dataset was subjected to more

multivariate analyses, and a four factor PCA was extracted that accounted for 84% of the variance, almost a 20% increase from the previous PCA (Table 2). The first factor was highly loaded with Al, Cr, Ni and Pb. The second factor was loaded primarily with Ca and Cd. The third factor was loaded with P, K and Mn, while the fourth factor had only one element, Na.

The first factor has declined remarkably since 1992, primarily due to the decrease in Pb in the environment (Fig 3). The other three elements may also be decreasing over time due to declines in the amount of dust, as discussed in our last report, however this factor does not show a significant changes from west to east (Fig. 4). Factor 2, Ca and Cd, shows a small increase over time although the data appear to cycle a bit between years. No significant west to east change appears for these elements either. The nutrition factor, Factor 3, shows a highly significant increase over time, mainly due to a large increase between 1992 and 1997 that has been sustained in 2002. There is a small increase in this factor from west to east, although it is a bit ambiguous given the low levels at Saganaga Lake. The Na factor reversed a decline over time by increasing significantly in 2002. It is the only factor that shows a consistent decline from west to east. Scores for all four factors differed statistically significantly over years and localities (F probabilities < 0.000) except for Factor 1 over localities (F probability $= 0.417$) using three-way analyses of variance.

Cd does not appear to be a problem for *Hypogymnia physodes* any longer (Fig. 5), but Ca, Mg and Mn continue to be above the enrichment thresholds discussed in the last report. A dramatic decrease in Pb in this species is also evident. Mg also appears to be increasing a small amount each sampling period. Ca and Mg are alkaline earth elements, and their increase may reflect a trend from deposition of alkaline elements from some unknown source. For the first three years of sampling the highest Mg concentrations were at Lac La Croix, but in the last year Isabella Lake had the highest Mg concentrations. Lac La Croix is also high in Na in some of the years and species.

CONCLUSIONS AND RECOMMENDATIONS

The 2002 sampling year has increased the duration of sampling to 16 years. Over this time interval the most dramatic change has been the decline in Pb. This decline continues and

has not leveled off. Future sampling will be able to determine when and if Pb in lichen tissues will level off.

The increase in alkali and alkaline earth metals over time has continued with no explanation. More detailed research is needed to determine the cause of this trend.

The decrease of sodium from west to east is highly significant across species. A source of sodium near Lac La Croix should be investigated. The unusually high levels of some elements at Isabella Lake continues to occur, and should also be investigated.

Evernia mesomorpha appears to take up elements in a different pattern than the other three species, with no explanation at this time. Further detailed research is needed to explore this phenomenon.

Hypogymnia physodes, an important biomonitoring species, continues to have elevated levels of Ca, Mg and Mn above enrichment thresholds based on the extensive literature on this species. We do not know if this reflects deposition from a source in the BWCA or an unusual affinity for these elements in the species.

It is recommended that sampling be repeated in 4-5 years in order to continue studies of these patterns and trends.

ACKNOWLEDGEMENTS

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Table 1. Element loadings in descending order on two components from a principal components analysis of element data for four lichen species sampled four times in the Boundary Waters Canoe Wilderness. Elements highly loaded on one component but not the other are shown in bold print.

Chemical element	Factor 1	Factor 2
Cr	**0.867**	-0.073
Al	**0.862**	0.188
S	**0.860**	0.017
Fe	**0.800**	0.054
B	**0.728**	0.179
Ni	**0.700**	0.363
Cu	0.613	0.573
P	0.537	0.545
K	0.532	0.712
Na	0.518	-0.415
Pb	0.330	0.590
Zn	0.449	0.805
Mg	0.141	**0.878**
Cd	-0.088	**0.830**
Mn	0.059	**0.807**
Ca	-0.237	**0.778**

Table 2. Element loadings in descending order on four factors from a principal components analysis of elemental data for three lichens species sampled four times in the Boundary Waters Canoe Wilderness. Elements highly loaded on one component but not others are shown in bold print.

Chemical element	Factor 1	Factor 2	Factor 3	Factor 4
Cr	**0.888**	0.013	0.263	0.204
Al	**0.860**	-0.120	0.339	0.159
Pb	**0.810**	0.363	-0.001	-0.183
Ni	**0.739**	0.297	0.204	0.458
Cu	0.681	0.290	0.543	-0.096
Fe	0.675	-0.113	0.360	0.285
S	0.582	0.052	0.636	0.337
B	0.573	-0.077	0.659	0.158
Zn	0.547	0.267	0.726	-0.025
Ca	0.032	**0.947**	-0.062	0.029
Cd	0.081	**0.894**	0.168	-0.003
Mg	0.158	0.677	0.512	0.255
P	0.337	-0.149	**0.885**	0.069
K	0.404	0.308	**0.747**	0.213
Mn	-0.057	0.440	**0.732**	0.030
Na	0.162	0.070	0.098	**0.908**

Fig. 1. Effects of year on Factors 1 and 2. Points are means with standard error bars. Lines are polynomial regressions fitted to the means to show trends.

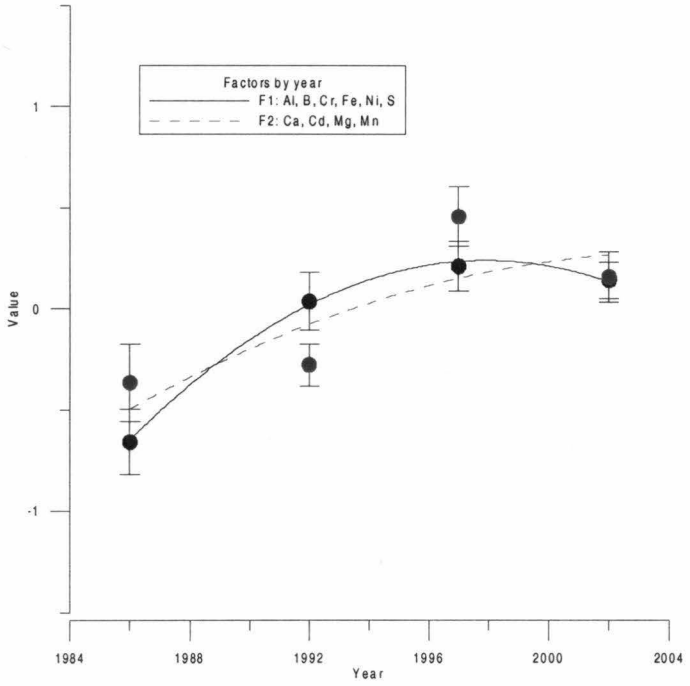


Fig. 2. Effects of locality on Factors 1 and 2. See legend for Fig. 1 for explanations of figure.

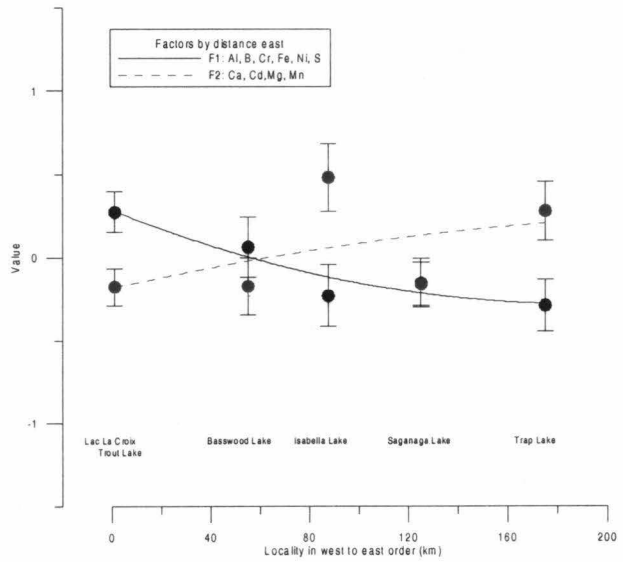


Fig. 3. Effects of year on Factors 1-4, 4 factor PCA. See legend for Fig. 1 for explanations of figure.

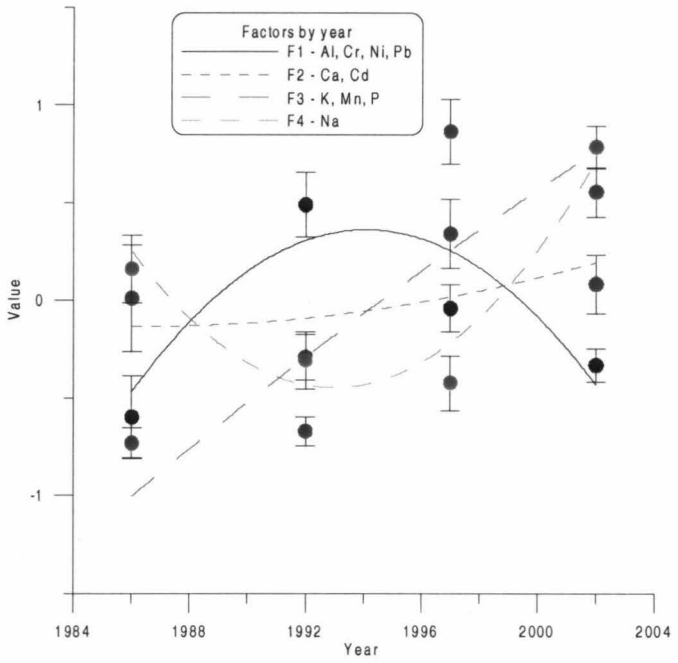


Fig. 4. Effects of locality on Factors 1-4, 4 factor PCA. See legend for Fig. 1 for explanations of figure.

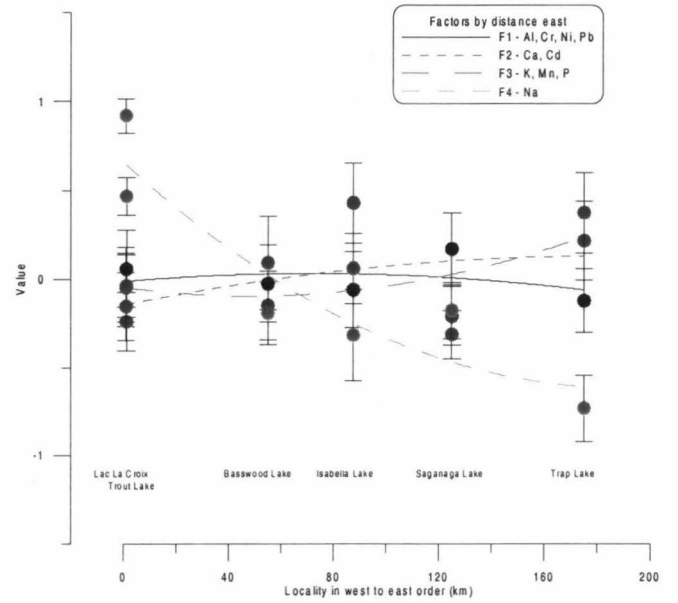
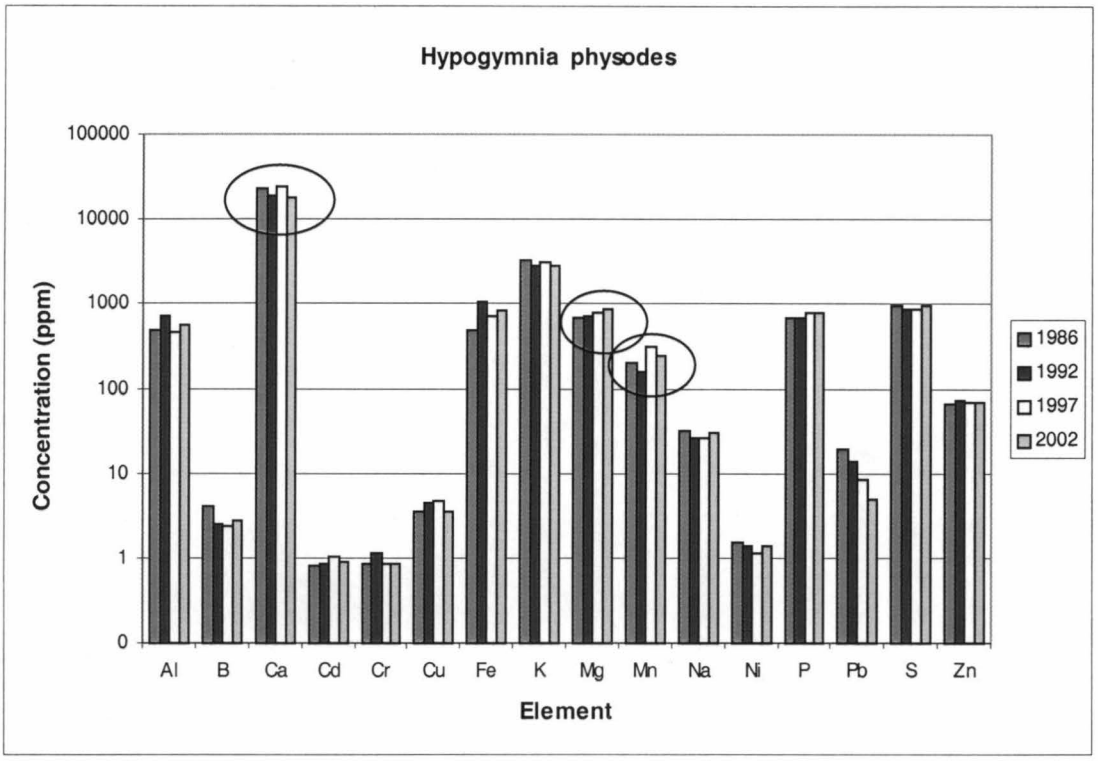


Fig. 5. Element concentrations over years in *Hypogymnia physodes*. Elements over enrichment thresholds are circled.



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APPENDIX 1

Latitudes and Longitudes of Elemental Analysis Localities

Locality	Latitude	Longitude
Basswood Lake	48°04'12"N	91°40'31"W
Isabella Lake	47°48'48"N	91°19'05"W
Lac La Croix	48°19'37"N	92°17'24"W
Saganaga Lake	48°13'27"N	90°52'33"W
Trap Lake	48°01'01"N	90°21'51"W
Trout Lake	47°55'45"N	92°17'42"W

Appendix 2 – 2002 Lichen Elemental Data

Sample	Loc	Species	Al	B	Ca	Cd	Cr	Cu	Fe	K	Mg	Mn	Na	Ni	P	Pb	S	Zn
1	Saganaga	CLRA	212.800	1.950	726.160		0.327	0.772	208.410	925.940	181.580	34.895	17.566		301.380		395	10.947
2	Saganaga	CLRA	234.120	1.379	697.230		0.360	0.910	230.180	953.340	184.300	32.823	17.216	0.506	293.210		440	10.938
3	Saganaga	CLRA	228.080	1.147	680.050		0.405	0.856	253.980	913.290	180.810	34.878	15.119	0.499	305.180		490	10.580
4	Trapp L	CLRA	282.880	1.301	955.670	0.121	0.436	1.281	264.170	1657.300	392.100	72.448	20.725	0.456	613.960		630	19.857
5	Trapp L	CLRA	260.170	1.231	953.540		0.447	1.286	244.480	1394.300	348.520	64.240	18.142	0.452	516.940		410	18.909
6	Trapp L	CLRA	243.700	1.081	930.950		0.391	1.153	229.250	1458.000	341.500	66.011	18.450	0.457	494.170		470	18.430
7	Basswood	CLRA	241.760	0.624	600.830		0.402	0.845	340.810	834.650	191.340	28.343	14.755	0.472	228.530		250	10.500
8	Basswood	CLRA	235.440	0.655	637.080		0.433	0.936	337.540	851.230	203.100	27.547	16.455		235.930		600	10.179
9	Basswood	CLRA	241.450	0.820	595.880		0.428	0.850	338.580	802.910	186.500	24.201	15.026		229.640		365	9.555
10	Basswood	CLRA	296.400	0.755	659.940		0.451	1.062	427.960	821.920	194.790	24.319	18.413	0.510	248.270		380	9.784
11	Basswood	CLRA	298.730	0.821	659.050		0.431	1.059	418.660	839.910	192.520	23.502	19.179	0.463	246.540		420	9.651
12	Basswood	CLRA	296.040	0.861	689.740		0.500	1.142	419.290	935.820	204.430	25.310	20.145	0.471	290.630		460	10.885
13	Lac La Croix	CLRA	207.080	0.870	774.110	0.124	0.369	1.187	289.270	1371.300	271.800	22.045	20.471		356.650		525	10.993
14	Lac La Croix	CLRA	176.930	0.703	781.940		0.373	1.217	246.610	1341.600	264.100	21.600	18.819		374.480		560	10.933
15	Lac La Croix	CLRA	196.580	0.793	714.170	0.130	0.351	1.338	276.810	1567.700	289.940	24.567	22.374		427.300		540	12.839
16	Lac La Croix	CLRA	187.200	0.786	688.520		0.383	1.096	261.240	1196.600	252.340	22.317	19.413		319.010		550	10.906
17	Lac La Croix	CLRA	208.220	0.727	607.210		0.399	0.962	299.920	993.660	233.160	19.711	20.380		293.220		1050	9.484
18	Lac La Croix	CLRA	211.740	0.797	619.870			1.005	288.710	1084.400	239.410	19.982	20.973		297.490		760	10.156
19	Trout L	CLRA	353.950	1.394	1073.800		0.547	1.662	760.910	2117.300	413.040	138.000	34.514	0.485	899.050		670	19.207
20	Trout L	CLRA	351.020	1.385	1120.900		0.494	1.604	760.450	2062.400	413.490	148.210	31.731	0.524	826.610		670	19.066
21	Trout L	CLRA	332.410	1.302	1149.600		0.566	1.698	749.940	2266.400	412.850	144.260	30.924	0.483	919.060		665	20.308
22	Isabella	CLRA	352.790	0.863	693.080		0.389	0.856	403.650	794.310	235.030	21.995	22.379		223.700		540	8.399
23	Isabella	CLRA	378.950	0.944	703.170		0.411	0.929	440.360	863.600	248.730	23.928	23.528		254.490		630	8.939
24	Isabella	CLRA	414.920	1.005	652.240		0.481	0.925	483.180	710.250	235.970	21.951	23.244	0.498	222.890		590	8.529
25	Saganaga	EVME	424.550	2.859	1286.500		0.607	2.091	511.020	1994.600	306.730	43.510	30.015	0.744	507.710	1.712	1080	31.304
26	Saganaga	EVME	459.930	3.065	1238.300	0.120	0.700	2.123	588.150	1936.000	314.630	42.093	31.646	0.829	493.420	1.668	1135	30.574
27	Saganaga	EVME	448.690	3.263	1173.800	0.126	0.647	2.228	557.070	2010.700	331.180	45.528	30.153	0.873	536.220		1240	29.304
28	Trapp L	EVME	505.620	3.388	1676.200	0.238	0.910	2.560	631.090	2112.900	337.450	31.114	34.871	0.849	567.410	1.677	1170	28.859
29	Trapp L	EVME	579.900	3.416	1735.600	0.242	0.854	2.779	692.600	2112.000	358.200	33.282	37.549	1.003	561.330	2.028	1210	30.157
30	Trapp L	EVME	529.850	3.323	1803.200	0.271	0.883	2.653	654.290	2045.200	345.830	30.844	32.798	1.002	543.780	2.265	1155	30.256
31	Basswood	EVME	552.930	2.683	975.460	0.196	0.870	2.353	1009.900	1687.200	279.940	27.121	44.196	1.239	439.890	2.850	1290	25.850

32	Basswood	EVME	571.410	2.440	773.140	0.184	0.892	2.344	1136.000	1735.700	291.350	28.708	43.240	1.242	420.480	2.630	1200	28.232
33	Basswood	EVME	579.780	2.677	878.760	0.191	1.023	2.459	1096.700	1677.800	288.360	27.458	53.620	1.228	455.260	3.018	1140	30.343
34	Lac La Croix	EVME	773.400	3.745	1953.900	0.237	1.270	2.918	1259.300	2443.100	458.190	33.580	40.089	1.337	794.410	2.850	1480	32.037
35	Lac La Croix	EVME	828.600	4.363	1543.600	0.244	1.398	3.024	1506.600	2497.700	474.250	34.169	46.342	1.400	740.400	2.186	1520	30.181
36	Lac La Croix	EVME	807.450	3.804	1908.700	0.236	1.281	2.952	1439.500	2226.500	442.890	32.323	39.753	1.536	614.230	2.273	1480	28.174
37	Trout L	EVME	537.610	2.459	7474.200	0.303	0.946	2.573	1270.600	3160.300	529.310	149.090	39.098	1.330	1009.500	1.943	1140	42.818
38	Trout L	EVME	486.370	2.025	5440.200	0.277	0.887	2.526	1235.600	3329.400	558.940	154.810	39.666	1.309	1203.900	1.666	1120	41.627
39	Trout L	EVME	507.190	2.437	6026.100	0.253	0.879	2.512	1273.800	2936.300	455.130	117.730	38.653	1.531	900.520	1.780	1130	38.729
40	Isabella	EVME	249.110	1.909	5407.100	0.248	0.459	4.469	309.670	1804.600	370.500	92.876	19.185	0.744	469.380		690	27.521
41	Isabella	EVME	287.950	2.019	4100.600	0.225	0.519	1.672	343.990	1791.400	375.270	85.336	20.661	0.836	472.070		690	29.076
42	Isabella	EVME	267.380	1.944	6684.400	0.307	0.376	1.702	283.250	1951.100	413.670	104.010	19.797	0.802	541.890		810	29.017
43	Saganaga	HYPH	626.540	3.271	17171.000	0.446	0.939	3.455	891.980	2500.000	780.120	242.050	29.990	1.467	633.430	6.480	970	61.802
44	Saganaga	HYPH	737.210	3.172	21139.000	0.512	1.131	3.871	1096.200	2362.700	735.790	168.590	29.599	1.533	670.010	9.174	980	57.439
45	Saganaga	HYPH	466.790	2.543	23490.000	0.425	0.695	3.341	653.780	2388.000	677.220	221.420	27.521	1.261	544.260	5.560	860	66.315
46	Trapp L	HYPH	553.210	2.731	17384.000	1.632	0.776	4.025	638.290	2811.500	789.590	247.150	30.743	1.094	734.410	4.103	910	87.994
47	Trapp L	HYPH	520.500	2.617	15688.000	1.387	0.831	3.373	599.040	3036.500	940.830	240.700	35.273	1.207	884.460	3.494	910	91.311
48	Trapp L	HYPH	509.800	2.726	19577.000	2.024	0.741	3.380	582.160	2740.400	834.500	290.320	32.480	1.129	655.280	3.835	870	85.032
49	Basswood	HYPH	625.800	2.303	14772.000	0.730	0.892	3.156	1030.900	2730.000	690.460	181.960	29.167	1.280	769.260	5.606	1120	57.583
50	Basswood	HYPH	735.710	2.951	21944.000	1.049	1.084	3.771	1120.600	2895.700	714.580	226.460	34.128	1.672	758.550	7.610	990	65.344
51	Basswood	HYPH	601.160	1.979	14184.000	0.584	0.919	2.809	1033.900	3312.600	825.230	210.490	28.912	1.181	968.430	4.571	990	57.078
52	Lac La Croix	HYPH	538.120	2.027	19152.000	1.005	0.863	3.440	775.890	2741.700	998.120	146.820	28.709	1.491	821.520	5.138	1080	58.188
53	Lac La Croix	HYPH	483.990	1.952	10987.000	0.555	0.768	2.755	693.900	2934.200	918.410	156.560	25.636	1.189	957.010	3.192	890	45.200
54	Lac La Croix	HYPH	601.380	1.955	14211.000	0.562	1.003	3.004	944.030	2642.900	988.580	144.080	33.124	1.769	750.310	5.674	1070	43.596
55	Trout L	HYPH	373.970	2.410	18334.000	0.816	0.667	3.428	732.790	3602.700	848.380	286.000	31.188	1.097	1017.800	3.853	870	70.887
56	Trout L	HYPH	528.420	2.858	14169.000	0.998	0.902	4.042	1185.900	3211.800	749.080	228.330	31.145	1.305	809.010	4.368	980	66.580
57	Trout L	HYPH	439.330	2.519	15184.000	0.913	0.757	3.648	854.080	3292.200	816.540	231.780	31.120	1.211	893.250	4.568	1030	69.525
58	Isabella	HYPH	571.810	3.779	24640.000	0.973	0.862	3.714	680.890	3004.100	1352.700	385.420	32.323	1.938	976.540	4.570	890	79.797
59	Isabella	HYPH	573.080	3.538	21054.000	0.906	0.799	3.581	676.060	2788.000	1179.100	387.710	28.408	1.835	836.670	4.495	850	70.551
60	Isabella	HYPH	561.060	3.795	24912.000	1.021	0.786	3.880	696.860	2884.900	1197.100	378.620	32.494	1.770	912.770	5.212	920	84.387
61	Saganaga	PASU	700.040	4.829	4726.600	0.180	0.924	4.199	845.370	2549.600	577.270	206.250	26.020	1.397	953.740	7.318	1035	91.946
62	Saganaga	PASU	630.870	4.595	4770.500	0.147	0.889	3.704	755.060	2679.800	537.570	161.420	29.421	1.245	899.250	6.241	1050	86.044
63	Saganaga	PASU	510.360	3.463	4002.700	0.186	0.749	3.157	616.900	2739.600	517.590	149.530	26.169	1.166	916.880	4.590	1040	66.469
64	Trapp L	PASU	826.880	4.394	2829.000	0.635	1.097	4.752	902.960	3160.400	622.150	175.140	31.680	1.310	1279.900	5.989	1200	100.100
65	Trapp L	PASU	857.540	4.630	4255.600	0.689	1.189	4.669	957.670	3323.800	779.110	243.950	32.179	1.305	1541.300	5.729	1115	112.150

66	Trapp L	PASU	818.880	4.251	3227.800	0.644	1.146	4.572	921.950	3241.100	595.750	169.140	32.171	1.300	1296.200	4.811	1160	94.491
67	Basswood	PASU	643.020	4.860	4857.300	0.323	0.995	4.345	1128.300	3793.500	695.320	373.890	28.288	1.302	1450.800	4.944	1380	94.855
68	Basswood	PASU	808.190	5.455	5235.800	0.344	1.230	4.854	1424.000	3826.300	690.330	325.550	38.955	1.520	1465.300	5.027	1360	99.960
69	Basswood	PASU	694.880	4.627	4680.000	0.344	1.038	4.352	1180.100	3606.400	649.170	317.360	30.899	1.276	1424.500	4.523	1350	91.905
70	Lac La Croix	PASU	696.280	3.536	3312.500	0.424	1.085	4.406	955.050	2948.700	601.430	64.069	25.501	1.794	1088.900	5.910	1170	64.556
71	Lac La Croix	PASU	753.290	3.697	3447.100	0.428	1.140	4.044	1037.900	2925.000	676.490	76.010	27.524	1.749	1095.700	6.233	1225	59.110
72	Lac La Croix	PASU	584.760	3.603	3015.700	0.344	0.819	3.746	744.380	3025.500	646.620	64.434	26.583	1.365	1239.200	3.752	1190	54.684
73	Trout L	PASU	752.120	4.307	5042.800	0.546	1.149	4.182	1758.200	3336.200	728.330	422.310	27.143	1.364	1455.800	6.739	1190	82.943
74	Trout L	PASU	594.340	4.443	3866.000	0.462	0.971	3.964	1409.700	3557.500	670.880	333.890	25.535	1.162	1626.000	5.905	1220	85.269
75	Trout L	PASU	540.810	4.537	4114.600	0.575	0.965	3.977	1285.000	4089.400	763.040	359.820	26.966	1.164	1913.900	6.239	1220	93.774
76	Isabella	PASU	786.530	5.779	4776.200	0.609	0.980	4.694	943.230	3022.200	822.520	260.000	37.378	1.759	1321.800	6.754	1170	84.982
77	Isabella	PASU	804.970	4.200	4978.800	0.393	0.894	5.015	815.780	2687.400	568.670	231.270	51.681	1.593	937.320	8.628	1180	85.492
78	Isabella	PASU	916.700	5.442	5091.200	0.569	1.092	5.229	1036.500	2967.900	738.300	256.660	42.965	1.748	1211.600	8.077	1170	87.453

Appendix 3 – Element means by species and year

Means by Localities (by species, by elements)
1986

Cladina rangiferina

	Lac La Croix	Trout Lake	Basswood Lake	Isabella Lake	Saganaga Lake	Trap Lake	Total average
Al	256.043	231.373	256.023	260.688	225.338	209.588	239.842
B	1.938	2.013	1.318	1.768	1.585	1.673	1.715
Ca	529.070	607.373	455.233	600.793	494.640	739.515	571.104
Cd	0.135	0.123	0.143	0.168	0.178	0.150	0.149
Cr	0.438	0.423	0.428	0.393	0.398	0.403	0.413
Cu	1.383	1.633	1.360	1.598	1.535	2.093	1.600
Fe	213.440	262.833	210.220	213.630	171.783	155.980	204.648
K	1821.700	2327.775	1496.450	1568.425	1505.375	2327.625	1841.225
Mg	315.145	330.740	229.755	254.468	244.665	345.913	286.781
Mn	26.680	57.853	59.485	47.460	27.635	52.395	45.251
Na	27.548	31.520	24.493	28.035	25.488	26.750	27.356
Ni	0.568	0.608	0.673	0.570	0.560	0.595	0.595
P	497.270	638.990	367.120	335.165	392.158	770.335	500.173
Pb	1.078	0.958	1.540	1.558	2.183	1.215	1.422
S	461.250	490.000	435.000	470.000	460.000	512.500	471.458
Zn	12.535	16.740	14.198	16.600	13.690	20.185	15.658

Evernia mesomorpha

	Lac La Croix	Trout Lake	Basswood Lake	Isabella Lake	Saganaga Lake	Trap Lake	Total average
Al	966.315	577.638	660.103	644.585	492.603	371.480	608.765
B	6.590	4.935	6.038	4.883	5.395	5.020	5.411
Ca	1159.150	656.940	779.845	1524.150	676.978	1006.350	944.133
Cd	0.300	0.163	0.210	0.155	0.333	0.165	0.219
Cr	1.540	0.990	1.058	0.963	1.005	0.665	1.024
Cu	3.340	2.143	3.003	2.773	2.360	2.510	2.641
Fe	1037.445	667.558	726.440	584.675	429.188	295.800	614.897
K	2745.950	1825.900	2379.650	2057.125	2324.175	2561.800	2248.145

Mg	479.430	290.165	343.223	355.135	310.500	277.260	335.474
Mn	23.765	31.595	25.395	69.035	67.270	29.745	44.010
Na	50.355	38.335	38.788	25.380	45.293	26.075	37.202
Ni	1.155	0.963	0.943	0.780	1.085	0.695	0.939
P	603.120	383.173	481.905	398.083	520.823	534.070	470.516
Pb	5.285	6.508	4.873	6.060	4.965	4.410	5.451
S	1372.500	1028.750	1221.250	1005.000	1041.250	947.500	1091.250
Zn	29.035	24.250	30.115	32.623	27.438	34.085	29.197

Hypogymnia physodes

	Lac La Croix	Trout Lake	Basswood Lake	Isabella Lake	Saganaga Lake	Trap Lake	Total average
Al	582.040	485.783	529.800	577.420	461.410	321.360	480.379
B	4.770	4.118	4.135	4.530	3.633	4.098	4.166
Ca	22004.000	19688.250	15432.000	34218.000	20374.750	25072.000	23614.200
Cd	0.650	0.633	0.760	1.350	0.708	0.785	0.836
Cr	1.025	0.978	0.925	0.885	0.888	0.625	0.870
Cu	5.519	3.010	3.175	3.805	2.780	3.940	3.576
Fe	587.550	587.875	508.480	586.405	431.055	294.765	489.623
K	3775.100	3498.900	3326.350	2809.450	3189.750	3454.800	3300.725
Mg	905.245	695.480	662.865	806.870	617.270	572.098	695.155
Mn	134.500	187.545	146.175	330.105	271.250	97.060	205.260
Na	32.945	32.510	32.620	22.670	40.570	27.500	31.207
Ni	1.565	1.658	1.630	1.660	1.555	1.263	1.547
P	929.220	711.645	680.635	551.655	724.443	720.850	702.704
Pb	20.795	15.775	16.110	26.940	18.018	18.435	19.524
S	1032.500	1061.250	915.000	802.500	1013.750	903.750	951.000
Zn	47.325	56.995	64.215	68.270	63.030	88.418	66.497

Means by Localities (by species, by elements)
1992

Cladina rangiferina

	Lac La Croix	Trout Lake	Basswood Lake	Isabella Lake	Saganaga Lake	Trap Lake	Total average
Al	388.377	451.200	261.710	276.243	359.087	310.183	341.133
B	1.289	1.494	1.211	1.034	1.286	1.123	1.240
Ca	398.723	657.793	667.877	1043.287	754.443	1031.037	758.860
Cd	0.200	0.124	0.163	0.157	0.139	0.201	0.164
Cr	0.724	0.627	0.535	0.497	0.554	0.614	0.592
Cu	1.648	1.870	1.498	1.578	1.493	1.873	1.660
Fe	543.237	944.243	333.553	246.617	351.620	277.290	449.427
K	998.290	1894.767	1024.863	1271.367	1444.667	1519.367	1358.887
Mg	238.247	380.063	278.900	531.717	321.613	390.363	356.817
Mn	15.105	34.019	90.936	40.788	83.457	47.414	51.953
Na	35.875	29.825	16.178	13.213	15.961	17.362	21.402
Ni	0.753	0.623	0.506	0.432	0.531	0.564	0.568
P	294.020	382.753	326.863	503.673	541.390	545.307	432.334
Pb	2.872	1.719	2.048	1.743	2.208	2.228	2.136
S	409.333	794.000	277.333	359.000	372.667	466.333	446.444
Zn	11.370	29.397	14.414	18.604	14.691	20.878	18.226

Evernia mesomorpha

	Lac La Croix	Trout Lake	Basswood Lake	Isabella Lake	Saganaga Lake	Trap Lake	Total average
Al	859.847	633.163	700.023	762.200	596.077	460.117	668.571
B	3.735	3.269	3.077	2.573	3.830	2.314	3.133
Ca	1057.763	996.850	695.907	643.827	1577.767	966.833	989.824
Cd	0.434	0.178	0.236	0.395	0.151	0.293	0.281
Cr	2.012	1.327	1.506	1.651	1.064	1.038	1.433
Cu	3.585	3.061	3.757	4.809	2.595	3.232	3.506
Fe	1344.133	1389.867	1287.833	901.853	723.267	498.257	1024.202

K	2549.633	2122.567	2054.067	2346.400	2388.500	2266.500	2287.944
Mg	438.490	366.837	370.243	367.880	371.853	329.940	374.207
Mn	38.571	33.947	28.008	20.760	32.262	28.099	30.274
Na	76.525	45.588	46.173	41.827	31.707	31.892	45.619
Ni	1.575	1.075	1.185	1.566	0.876	0.845	1.187
P	699.930	528.110	499.410	559.730	589.207	553.757	571.691
Pb	5.579	4.740	4.805	10.133	4.403	3.976	5.606
S	1143.333	1173.333	1146.667	1273.333	1104.000	990.333	1138.500
Zn	39.006	33.948	37.453	38.877	35.670	38.833	37.298

Hypogymnia physodes

	Lac La Croix	Trout Lake	Basswood Lake	Isabella Lake	Saganaga Lake	Trap Lake	Total average
Al	780.917	675.957	851.973	604.260	820.593	619.013	725.452
B	2.770	2.612	2.681	1.873	3.203	2.250	2.565
Ca	22106.000	23902.000	15934.333	19237.333	18561.667	13434.333	18862.611
Cd	1.314	0.512	1.035	1.041	0.593	0.725	0.870
Cr	1.188	1.070	1.267	0.950	1.424	0.847	1.124
Cu	4.193	3.919	4.326	5.507	4.542	4.698	4.531
Fe	1233.967	1514.567	1379.733	680.563	988.950	692.907	1081.781
K	3106.000	2683.667	3003.200	2693.133	2519.000	2898.367	2817.228
Mg	854.573	692.357	736.540	792.993	652.550	597.753	721.128
Mn	222.713	181.757	143.010	111.883	182.433	107.450	158.208
Na	31.102	27.317	25.951	21.634	29.626	20.345	25.996
Ni	1.588	1.419	1.455	1.015	1.732	1.283	1.415
P	732.520	641.147	711.600	682.560	647.523	705.170	686.753
Pb	11.488	9.347	13.627	16.143	18.013	15.135	13.959
S	934.333	966.000	942.000	751.667	875.333	922.333	898.611
Zn	72.233	71.780	68.996	72.533	71.731	74.872	72.024

Parmelia sulcata

	Lac La Croix	Trout Lake	Basswood Lake	Isabella Lake	Saganaga Lake	Trap Lake	Total average
Al	1055.61	1036.033	1202.800	871.293	1152.933	882.587	1033.543
B	3.93	5.115	4.076	3.475	4.691	4.507	4.299
Ca	2646.23	4380.533	2540.233	4462.533	3451.800	2931.300	3402.106
Cd	0.48	0.364	0.482	0.591	0.397	0.488	0.468
Cr	1.34	1.531	1.465	1.418	1.400	1.121	1.380
Cu	4.38	4.123	5.384	6.867	4.434	5.891	5.181
Fe	1368.73	1866.900	1455.333	910.447	1197.233	818.413	1269.510
K	3401.43	3239.400	2906.733	2698.433	3143.200	3271.333	3110.089
Mg	618.27	647.710	511.547	552.187	563.810	632.700	587.705
Mn	109.39	137.923	94.693	103.893	199.343	97.625	123.811
Na	38.10	33.448	29.042	27.642	25.912	20.662	29.134
Ni	1.75	1.977	1.594	1.663	1.550	1.429	1.661
P	1231.80	1286.300	998.197	895.220	1149.733	1439.733	1166.831
Pb	13.29	15.461	14.793	19.527	16.889	19.440	16.399
S	1216.66	1061.667	1146.667	998.667	1080.000	1031.667	1089.222
Zn	73.58	83.078	77.246	86.719	85.155	107.627	85.568

Means by Localities (by species, by elements)
1997

Cladina rangiferina

	Lac La Croix	Trout Lake	Basswood Lake	Isabella Lake	Saganaga Lake	Trap Lake	Total average
Al	291.06	193.400	209.617	256.667	251.700	234.833	239.547
B	0.93	1.219	0.603	0.620	1.753	1.293	1.070
Ca	755.80	766.133	764.983	620.633	545.367	1084.000	756.153
Cd		0.115				0.147	0.131
Cr	0.57	0.427	0.423	0.387	0.407	0.540	0.459
Cu	1.55	1.872	1.363	1.260	1.286	2.106	1.573
Fe	547.40	597.233	414.300	329.100	303.333	282.700	412.344

K	1557.33	2058.667	1325.000	1064.333	1412.333	2224.333	1607.000
Mg	328.20	328.200	235.017	259.867	253.800	403.467	301.425
Mn	61.61	55.926	46.572	29.057	53.019	37.495	47.280
Na	22.17	20.698	15.413	15.842	16.955	17.738	18.136
Ni	0.46	0.540				0.533	0.511
P	538.96	652.100	463.000	293.967	448.000	890.500	547.756
Pb							
S	482.22	520.000	413.333	390.000	501.667	666.667	495.648
Zn	16.91	18.373	15.936	9.330	16.042	23.390	16.664

Evernia mesomorpha

	Lac La Croix	Trout Lake	Basswood Lake	Isabella Lake	Saganaga Lake	Trap Lake	Total average
Al	710.80	422.500	526.100	252.100	484.767	444.133	473.400
B	3.37	3.333	3.126	1.613	2.643	2.535	2.771
Ca	1197.66	2971.667	938.433	2689.333	1079.000	2160.333	1839.406
Cd	0.23	0.213	0.240	0.200	0.142	0.287	0.219
Cr	1.42	1.100	1.187	0.660	1.065	1.476	1.152
Cu	4.26	3.853	4.879	3.059	4.530	5.582	4.361
Fe	1269.33	1369.333	1338.000	367.400	752.133	575.100	945.217
K	2699.00	2955.667	2088.333	2492.333	2082.000	2623.333	2490.111
Mg	428.80	398.833	322.500	434.900	320.967	375.100	380.183
Mn	30.51	57.135	38.406	119.900	43.739	60.048	58.291
Na	45.91	32.065	43.091	20.208	33.688	30.497	34.243
Ni	1.17	1.007	1.567	0.553	1.343	1.673	1.220
P	639.66	765.267	516.667	639.333	625.900	858.283	674.186
Pb	2.97	2.126	2.806		2.634	3.339	2.777
S	1400.00	1315.000	1180.000	753.333	1216.667	980.000	1140.833
Zn	31.44	34.785	28.928	31.631	28.720	45.130	33.440

Hypogymnia physodes

	Lac La Croix	Trout Lake	Basswood Lake	Isabella Lake	Saganaga Lake	Trap Lake	Total average
Al	383.867	412.467	459.433	641.033	534.433	368.167	466.567
B	2.346	2.143	2.079	2.918	2.472	2.246	2.367
Ca	24611.667	25065.000	26646.667	17493.333	24408.333	30840.000	24844.167
Cd	1.007	0.630	1.353	1.152	0.703	1.326	1.029
Cr	0.850	0.793	0.800	0.999	0.956	0.627	0.837
Cu	4.599	4.378	4.331	4.937	4.874	4.992	4.685
Fe	670.917	1080.300	726.233	807.333	720.717	420.067	737.594
K	3853.833	2909.667	2985.333	3220.667	2754.167	3096.000	3136.611
Mg	1054.767	701.767	643.667	933.733	682.600	657.800	779.056
Mn	379.250	131.717	308.033	593.533	252.883	219.700	314.186
Na	34.100	24.009	23.529	25.969	24.941	21.261	25.635
Ni	1.353	1.220	1.013	1.272	1.202	0.960	1.170
P	1040.167	568.950	799.500	890.533	697.833	885.033	813.669
Pb	5.822	7.074	9.389	8.908	9.772	9.744	8.451
S	963.333	900.000	790.000	813.333	986.667	785.000	873.056
Zn	63.071	56.295	59.626	91.679	62.593	90.409	70.612

Parmelia sulcata

	Lac La Croix	Trout Lake	Basswood Lake	Isabella Lake	Saganaga Lake	Trap Lake	Total average
Al	837.000	839.367	824.467	784.700	809.033	823.183	819.625
B	4.033	4.395	4.231	4.872	4.458	6.718	4.785
Ca	3444.667	4504.667	3536.000	4212.667	4249.333	4933.667	4146.833
Cd	0.333	0.357	0.487	0.767	0.273	0.563	0.463
Cr	1.253	1.246	1.093	0.920	1.066	1.123	1.117
Cu	5.633	4.922	4.931	4.992	5.005	6.691	5.362
Fe	1480.667	2009.500	1409.333	889.867	992.600	954.867	1289.472
K	4433.667	3046.167	3589.667	3454.000	3022.667	4109.500	3609.278
Mg	778.200	558.017	635.567	732.533	554.867	851.650	685.139
Mn	162.667	160.583	587.000	343.567	243.067	281.367	296.375

Na	31.136	25.336	23.471	24.698	23.839	24.989	25.578
Ni	1.893	1.630	0.807	1.299	1.266	1.113	1.335
P	1675.333	945.167	1578.000	1450.000	1073.667	1973.167	1449.222
Pb	8.779	10.280	7.910	11.476	10.177	13.716	10.390
S	1523.333	1293.333	1106.667	1041.111	1137.222	1281.667	1230.556
Zn	75.737	87.038	104.867	95.435	87.037	131.917	97.005

Means by Localities (by species, by elements)
2002

Cladina rangiferina

	Lac La Croix	Trout Lake	Basswood Lake	Isabella Lake	Saganaga Lake	Trap Lake	Total average
Al	197.958	345.793	268.303	382.220	225.000	262.250	268.473
B	0.779	1.360	0.756	0.937	1.492	1.204	1.008
Ca	697.637	1114.767	640.420	682.830	701.147	946.720	765.197
Cd	0.127					0.121	0.125
Cr	0.375	0.536	0.441	0.427	0.364	0.425	0.425
Cu	1.134	1.655	0.982	0.903	0.846	1.240	1.110
Fe	277.093	757.100	380.473	442.397	230.857	245.967	373.932
K	1259.210	2148.700	847.740	789.387	930.857	1503.200	1198.255
Mg	258.458	413.127	195.447	239.910	182.230	360.707	262.973
Mn	21.704	143.490	25.537	22.625	34.199	67.566	45.295
Na	20.405	32.390	17.329	23.050	16.634	19.106	20.831
Ni		0.497	0.479	0.498	0.503	0.455	0.483
P	344.692	881.573	246.590	233.693	299.923	541.690	392.430
Pb							
S	664.167	668.333	412.500	586.667	441.667	503.333	544.167
Zn	10.885	19.527	10.092	8.622	10.822	19.065	12.499

Evernia mesomorpha

	Lac La Croix	Trout Lake	Basswood Lake	Isabella Lake	Saganaga Lake	Trap Lake	Total average
Al	803.150	510.390	568.040	268.147	444.390	538.45	522.096
B	3.971	2.307	2.600	1.957	3.062	3.37	2.879
Ca	1802.067	6313.500	875.787	5397.367	1232.867	1738.33	2893.320
Cd	0.239	0.278	0.190	0.260	0.123	0.25	0.229
Cr	1.316	0.904	0.928	0.451	0.651	0.88	0.856
Cu	2.965	2.537	2.385	2.614	2.147	2.66	2.552
Fe	1401.800	1260.000	1080.867	312.303	552.080	659.32	877.729
K	2389.100	3142.000	1700.233	1849.033	1980.433	2090.03	2191.806
Mg	458.443	514.460	286.550	386.480	317.513	347.16	385.101
Mn	33.357	140.543	27.762	94.074	43.710	31.74	61.866
Na	42.061	39.139	47.019	19.881	30.605	35.07	35.630
Ni	1.424	1.390	1.236	0.794	0.815	0.95	1.102
P	716.347	1037.973	438.543	494.447	512.450	557.50	626.211
Pb	2.436	1.796	2.833		1.690	1.99	2.182
S	1493.333	1130.000	1210.000	730.000	1151.667	1178.33	1148.889
Zn	30.131	41.058	28.142	28.538	30.394	29.75	31.337

Hypogymnia physodes

	Lac La Croix	Trout Lake	Basswood Lake	Isabella Lake	Saganaga Lake	Trap Lake	Total average
Al	541.163	447.240	654.223	568.650	610.180	527.83	558.216
B	1.978	2.596	2.411	3.704	2.995	2.69	2.729
Ca	14783.333	15895.667	16966.667	23535.333	20600.000	17549.66	18221.778
Cd	0.707	0.909	0.788	0.967	0.461	1.68	0.919
Cr	0.878	0.775	0.965	0.816	0.922	0.78	0.856
Cu	3.066	3.706	3.245	3.725	3.556	3.59	3.482
Fe	804.607	924.257	1061.800	684.603	880.653	606.49	827.069
K	2772.933	3368.900	2979.433	2892.333	2416.900	2862.80	2882.217
Mg	968.370	804.667	743.423	1242.967	731.043	854.97	890.907

Mn	149.153	248.703	206.303	383.917	210.687	259.39	243.026
Na	29.156	31.151	30.736	31.075	29.037	32.83	30.664
Ni	1.483	1.204	1.378	1.848	1.420	1.14	1.413
P	842.947	906.687	832.080	908.660	615.900	758.05	810.721
Pb	4.668	4.263	5.929	4.759	7.071	3.81	5.084
S	1013.333	960.000	1033.333	886.667	936.667	896.66	954.444
Zn	48.995	68.997	60.002	78.245	61.852	88.11	67.701

Parmelia sulcata

	Lac La Croix	Trout Lake	Basswood Lake	Isabella Lake	Saganaga Lake	Trap Lake	Total average
Al	678.110	629.090	715.363	836.067	613.757	834.43	717.803
B	3.612	4.429	4.981	5.140	4.296	4.42	4.480
Ca	3258.433	4341.133	4924.367	4948.733	4499.933	3437.46	4235.011
Cd	0.399	0.528	0.337	0.524	0.171	0.65	0.436
Cr	1.015	1.028	1.088	0.989	0.854	1.14	1.020
Cu	4.065	4.041	4.517	4.979	3.687	4.66	4.326
Fe	912.443	1484.300	1244.133	931.837	739.110	927.52	1039.892
K	2966.400	3661.033	3742.067	2892.500	2656.333	3241.76	3193.350
Mg	641.513	720.750	678.273	709.830	544.143	665.67	660.030
Mn	68.171	372.007	338.933	249.310	172.400	196.07	232.816
Na	26.536	26.548	32.714	44.008	27.203	32.01	31.503
Ni	1.636	1.230	1.366	1.700	1.269	1.30	1.418
P	1141.267	1665.233	1446.867	1156.907	923.290	1372.46	1284.338
Pb	5.298	6.294	4.831	7.820	6.050	5.51	5.967
S	1195.000	1210.000	1363.333	1173.333	1041.667	1158.33	1190.278
Zn	59.450	87.329	95.573	85.976	81.486	102.24	85.344